5. *Breast Milk Consumption Rate*

5.1 *Introduction*

Breast milk consumption is an indirect but important exposure pathway for some environmental contaminants. For example, some airborne toxicants (e.g., semi-volatile organic chemicals) deposited in the environment bio-magnify and become concentrated in human adipose tissue and breast milk lipid. Highly lipophilic, poorly metabolized chemicals such as TCDD, DDT and PCBs are sequestered in adipose tissue and only very slowly eliminated except during lactation. These toxicants in breast milk lipid appear to be in equilibrium with adipose tissue levels, and over time the breast-fed infant may receive a significant portion of the total maternal load. Hoover *et al.* (1991) found that for a toxicant such as TCDD, an infant's intake rate (pg/kg-day) via breast milk can be substantially greater than the mother's environmental intake rate (pg/kg-day). In order to estimate toxicant exposures through this pathway, an understanding of the amount of breast milk consumed by infants at different ages is needed. This is the emphasis of the following sections. Childhood exposures to toxicants via commercial milk are addressed in Chapter 7.

5.1.1 *Terminology*

Table 5.1 Breast-feeding terminology[a]

Term	Definition
Fully breast-fed	
Exclusively breast-fed	Breast milk is sole source of calories.
Almost exclusively breast-fed	Breast milk is primary if not sole milk source with no significant calories from other liquid or solid food sources.
Predominantly breast-fed	Breast milk is the primary if not sole milk source with significant calories from other liquid or solid food sources.
Partially breast-fed	Combined breast milk and other milk intake where non-breast milk (e.g., formula) is a significant milk source whether or not the infant is consuming significant calories from other liquid or solid food sources.
Token breast-feeding	Minimal, irregular or occasional breast-feeding contributing minimal nutrition and few calories.
Extended breast-feeding	Breast-feeding beyond 12 months of age.
Weaning	Discontinuation of breast-feeding.

[a] Adapted from Labbok and Krasovec (1990)

This chapter evaluates breast milk intake among the breast-fed infant population and the entire infant population. Because different and sometimes contradictory terms for various breast-feeding populations are used in the literature, specific terms and definitions have been adopted for use throughout this chapter (Table 5.1). Note that fully breast-fed infants are those that receive breast milk as the primary if not sole source of milk. Many infants receive only breast milk during the day with a bottle of formula during the night. These infants would fit into the category of "almost exclusively breast-fed." Older breast-fed infants who do not receive significant amounts of formula but do receive supplementary solid foods would fit into the category of "predominantly breast-fed." Distributions of intake levels for fully breast-fed infants and for the entire infant population are derived later in this chapter.

A few further words about units and nomenclature are provided to avoid confusion. Dose in toxicology and pharmacology is often normalized to the body weight of an individual: The amount received over a day is divided by the body weight, typically provided in kilograms. The units are "mg/kg-day" or "g/kg-day." Analogously, breast milk consumption can be expressed in terms of amount received by the infant divided by the infant's body weight in kilograms per day, e.g., in units g/kg-day or kg/kg-day. For comparison purposes, arithmetic mean, or the "average," and standard deviations for milk consumption reported in the published literature are also presented in this chapter. They are expressed here as "mean ± standard deviation." We calculate from raw data skewness as $n \quad {}^{n}_{i=1} [(x_i - x)/s]^3 / ((n-1)(n-2))$ and standard error as $s/\sqrt{n}$, where s is the standard deviation and n the size of the sample.

5.1.2 Existing Guidance and Reports

In the *Revised 1992 Risk Assessment Guidelines* of the California Air Pollution Control Officers Association (CAPCOA, 1993, p. E-II-20-21), breast milk intake is addressed via the food ingestion pathway. The formula presented for calculating lifetime exposure to a contaminant via human milk ingestion is

$$\text{Dose-Im} = \text{Cm} \times \text{BMI} \times \text{F} \times \text{YR} / (25{,}550 \times \text{ABW}). \qquad \text{(Eq. 5-1)}$$

Dose-Im is the dose averaged over the lifetime, expressed in units in mg/kg-day. Cm is the concentration of the contaminant in breast milk, which when not known is derived by taking into account the half-life of the compound in the body, the fraction partitioned to lipid, and other factors. BMI is the daily breast milk ingestion rate in kg/day, with a default estimate of 0.9 kg/day taken from Whitehead and Paul (1981) and Butte *et al.* (1984a). F is the frequency of intake in days per year with a CAPCOA default value of 365. YR is the breast-feeding period, with a default value of 1 year. ABW is the average infant body weight with a default value of 6.5 kg. The number 25,550 in the divisor is the number of days in a 70 year lifetime.

Smith (1987) provides a formula for calculating the concentration of highly lipophilic dioxins in breast milk from doses received by the mother. This formula is consistent with observations of partitioning of dioxins and furans among body tissues, and of breast milk lipid and maternal tissue levels, as discussed in Smith (1987).

$$\text{Cm} = \text{Emi} \times t_{1/2} \times f_1 \times f_3 / (0.693 f_2) \qquad \text{(Eq. 5-2)}$$

where:
Emi = average maternal intake of contaminants from all routes
$t_{1/2}$ = half-life of contaminant in mother
f_1 = fraction of contaminant that is stored in maternal fat, 0.8
f_3 = fraction of breast milk that is fat, 0.04
f_2 = fraction of mother's weight that is fat, 0.3

The values for f_1, f_2, f_3 were taken from Smith (1987). This approach has been adopted by CAPCOA which used similar values for f_1, f_2, f_3. An additional factor can be added to take into account absorption of the contaminant from ingested milk.

Under the CAPCOA model, the mother is assumed to give birth to the child at age 25. The mother's intake (Emi) from birth to age 25 is therefore used to calculate concentration in the milk. Obviously, maternal age at parturition varies considerably. The point estimate of 25 years was used as a representative age at parturition in the CAPCOA approach. It is noteworthy that in 1994 over 35% of births recorded in California were to women 30 years of age or older and over 12% were to women 35 years old or over (California Department of Health Services, 1996). Maternal age is an important consideration because older primiparous women have accumulated more environmental contaminants and thus have a greater Emi (see Section 5.5.2).

The DRAFT *Parameter Values and Ranges for CALTOX* developed by the California Department of Toxic Substances Control (DTSC, 1993) assumes a breast milk ingestion rate for infants up to 12 months of age of 0.11 kg/kg-day, with a coefficient of variation of 0.2. The central estimate is equivalent to 0.7 kg/day for infants weighing 6.5 kg.

The U.S. EPA (1989) *Exposure Factors Handbook* does not explicitly address exposures via the breast milk pathway. A recent update of the Handbook (U.S. EPA, 1997) developed by the U.S. EPA National Center for Environmental Assessment provides an extensive discussion of this pathway and recommends values for breast milk intake, lipid intake rate and lipid content. For breast milk intake, mean rates of 730 ml/day for infants under 6 months, and 678 ml/day for infants under 1 year of age have been recommended. These figures are the time weighted averages from 5 publications identified as "key studies" by the Agency: Butte *et al.* (1984a), Dewey and Lonnerdal (1983), Dewey *et al.* (1991a; 1991b), Neville *et al.* (1988), and Pao *et al.* (1980). Upper-percentile rates of 1029 ml/day for infants aged 1-6 months, and 1022 ml/day for 12 months of age were also recommended. The upper percentiles were characterized as the "mean plus 2 standard deviations." These estimates can be converted from ml to grams of breast milk by multiplying by 1.03.

The *Exposure Factors Handbook* (U.S. EPA, 1997) also recommended values for intake rates of lipids in breast milk. Values for infants under one year were based on data of Butte *et al.* (1984a) and the analysis of the Dewey *et al.* (1991a) study by Maxwell and Burmaster (1993). A lipid intake of 26 ml/day was recommended, with an upper percentile value of 40.4 ml/day ("based on the mean plus 2 standard deviations"). A value of 4% was recommended for breast milk lipid content based on data of the National Research Council (1991), Butte *et al.* (1984a), and Maxwell and Burmaster (1993).

The American Industrial Health Council (AIHC, 1994) does not address the breast milk exposure pathway in its *Exposure Factors Sourcebook*.

A detailed analysis of the breast milk pathway, which addressed several of the key factors contributing to variable intakes among individual infants, was published by Maxwell and

Burmaster (1993). These researchers estimated a distribution of lipid intake from breast milk ingested by children under one year of age. They report that, at any given time, "approximately 22% of infants under one year of age are being breast-fed, the remaining 78% have no exposure to chemicals in their mother's breast milk." They found the mean lipid intake among nursing infants to be characterized by a normal distribution with mean 26.81 g/day and standard deviation 7.39 g/day. Their results are based on the fraction of infants at different ages being breast-fed according to the reports of Ryan *et al.* (1991a, 1991b) and "on data for lipid intake from a sample of white, middle- to upper-income, highly educated women living near Davis, California" (Dewey *et al.*, 1991a).

The Maxwell and Burmaster study represents a careful distributional analysis of breast milk intake. There are, however, some features that limit its usefulness for evaluations of acute and chronic exposure of breast-fed infants to environmental toxicants. First, the study did not analyze data on breast milk intake during the first three months of life and instead extrapolated from the Davis study to predict intake during this period. Second, intake was expressed as amount per day, rather than amount per body weight per day; the latter would facilitate more accurate dose calculations. Third, estimates of the breast-feeding population are made for the fraction of current feeders on any given day rather than the fraction of infants who breast-fed at any time during their first year of life. For chronic exposure analyses it is important to consider the current in addition to prior intakes of individual infants. Finally, there are now data on breast-feeding in the Pacific states (U.S. census region) which appear to be more representative of the Californian population than the national figures used by Maxwell and Burmaster (1993).

For the point estimate approach, the basic CAPCOA algorithm (Eq. 5-3) is used to calculate chronic exposure. For the stochastic approach, the terms in the equation (Eq. 5-5) are altered to allow variation of breast milk intake as is discussed in Section 5.1.3. The chemicals to be analyzed in the breast milk exposure pathway are described in Appendix E and summarized in Table E.3. The algorithm for the point estimate approach to calculating dose via breast milk exposure is the same as that indicated by Equation 5-1, with the exception that breast milk ingestion rate is expressed as grams consumed per kilogram of infant body weight, instead of kg consumed.

Under the default assumptions, the infant consumes breast milk daily until one year of age at which point the infant is considered weaned. Exposure continues throughout life, which is assumed to end at age 70, the default life expectancy. Thus lifetime average daily dose from the breast milk pathway is given by

$$Dose_m = Cm \times BMI_{bw} / 70 \qquad \text{(Eq. 5-3)}$$

where $Dose_m$ = lifetime average dose received from contaminated breast milk
Cm = concentration of contaminant in breast milk, calculated as in Eq. 5-2.
BMI_{bw} = breast milk ingestion rate during the first year of life, in g/kg-day

The value of 70 in the divisor represents the assumed 70 year lifespan.

For acute and subchronic exposures, daily dose is given by:

$$Dose_m = Cm \times BMI_{bw} \qquad \text{(Eq. 5-4)}$$

5.1.3 Conceptual Framework for Considering Variable Breast Milk Consumption Rate

Building on the work of the U.S. EPA (1995) and Maxwell and Burmaster (1993), we use a stochastic approach to evaluate parameters related to contaminant intake via the breast milk pathway. Intake distributions are derived for nursing infants as well as the entire infant population in California. The following issues are addressed: 1) variable breast milk intake among individuals; 2) correlation of intake with the infant's body weight (*e.g.*, large babies consume greater amounts of milk than small ones); 3) variable consumption rate over the breast-feeding period; 4) fraction of the infant population nursing at different ages; and 5) frequency of breast-feeding in the Pacific states.

Variability in intake is explicitly addressed through the distributional approach. To account for the correlation of intake and body weight, consumption is evaluated in terms of amount consumed per body weight, and studies where both breast milk consumption and body weight were reported for each individual were used in evaluating the parameter. Variable intake with time can be addressed by allowing consumption to be a function of time, and assessing the impact of different ways of averaging over time on estimates of consumption.

Average dose ($Dose_m$) received via the breast milk pathway of an agent at concentration Cm in mother's milk can be expressed as:

$$Dose_m = \int_0^{T_b} [Cm(t) \times BMI_{bw}(t)]\, dt / AT, \qquad \text{(Eq. 5-5)}$$

where AT is the averaging time period and T_b is the age at weaning. $BMI_{bw}(t)$ is the consumption rate of milk in amount ingested per body weight per day (*e.g.*, g/kg-day). If lipid intake is of interest, the lipid concentration in mother's milk is inserted for Cm(t), lipid intake is inserted for $BMI_{bw}(t)$.

Concentration in mother's milk (Cm) is also affected by parity and maternal age. Although not taken into account in the above equations, it is should be noted that Cm will be greater for the first child compared to the second child and so on since lactation is the predominant mode of elimination of many highly lipophilic contaminants. Similarly, Cm will be greater in older mothers due to a longer period of maternal accumulation. We note that the initiation of breast-feeding in older mothers is higher than in other age groups and that the duration of breast-feeding is generally longer for infants of older mothers (see Section 5.5.2).

With respect to the term T_b in Eq. 5-5, Maxwell and Burmaster (1993) found that the 1989 national figures for the fraction of infants breast-feeding (f) was well described by a negative exponential (e.g., $f = a\, e^{-c\,t}$). We have found that this also holds for the most recent

(1995) data for the Pacific states region. The Pacific states data are used to describe the population distribution for T_b, (Section 5.3) and together with the information on variable intake in breast-feeding infants at different ages, to describe the distribution of milk and lipid intake over the entire infant population (Section 5.3.2).

5.2 Breast Milk Consumption Among Breast-feeding Infants

5.2.1 Literature Review and Evaluation of Breast Milk Consumption Studies

Breast milk intake studies were identified through computerized literature searches, references found in articles reviewed, and references from personal communications with researchers. The criteria used to identify studies for review were: 1) the use of 24-hour test weighings to measure milk intake (see below); 2) the analysis of primary data (*i.e.*, not review articles) and 3) the consumption of milk directly from the breast. The following studies were identified for review: Pao *et al.* (1980); Whitehead and Paul (1981); Hofvander *et al.* (1982); Dewey and Lonnerdal (1983); Butte *et al.* (1984a); Kohler *et al.* (1984); Salmenpera *et al.* (1985); Borschel *et al.* (1986); Matheny and Picciano (1986); Neville *et al.* (1988); Stuff and Nichols (1989); Dewey *et al.* (1991a; 1991b); Ferris *et al.* (1993) [referent group]; and Michaelson *et al.* (1994). In those studies that include reported health status of mothers and infants, mothers were described as healthy, well-nourished, and at or near normal body weight. Infants were described as healthy, near- or full-term, and single born. The studies are briefly described in Table 5.2 and are divided into two categories: those for which breast milk intake is reported as amount (e.g., ml or grams) per day and those for which intake is reported as amount per body weight per day.

Table 5.2 Studies of Breast Milk Intake

Study	Number of Infants*	Infant Age at Measurement and Study Population	Comments
Intake reported as amount per day:			
Pao *et al.* (1980)	22	1, 3, 6, 9 months. Southwestern Ohio. Predominantly white, middle class.	Summary results only. Exclusively and partially breast-fed infants. Weight provided separately. After 1 month of age few exclusively breast-fed infants.
Whitehead and Paul (1981)	48	1 - 8 months. Cambridge, England.	Summary results only. Exclusively and partially breast-fed infants.
Dewey and Lonnerdal (1983)	20	1 - 6 months. Davis, CA. University community.	Summary results only. Exclusively and almost exclusively breast-fed infants.
Kohler *et al.* (1984)	26	6, 14, 22, 26 weeks. Lund, Sweden. Suburban community.	Summary results only. Exclusively breast-fed infants.
Matheny & Picciano (1986)	50	2-16 weeks. Champaign-Urbana, Illinois.	Summary results only. Compilation of three studies from the same laboratory.
Neville *et al.* (1988)	13	Throughout 1st year. Denver, Colorado. Caucasian, mid- to upper-socioeconomic status.	Summary results only. Exclusively or almost exclusively breast-fed for at least 5 months and predominantly breast-fed until 12 months of age.
Intake reported on a body weight basis:			
Hofvander *et al.* (1982)	75	1, 2, 3 months (25 infants at each month). Uppsala, Sweden.	Individual data available. Exclusively breast-fed infants.
Butte *et al.* (1984a)	45	1, 2, 3, 4 months. Houston, Texas. Mostly Caucasian, mid- to upper- socioeconomic stratum; high educational status.	Summary results only. Exclusively and almost exclusively breast-fed infants.
Salmenpera *et al.* (1985)	31	4, 6, 9 and 10-12 months. Helsinki, Finland.	Summary results only. Exclusively breast-fed infants.
Borschel *et al.* (1986)	15	1, 2, 4, 6 months. Lafayette, Indiana. University community.	Summary results only. Breast-fed infants. Supplemental solid or liquid foods not reported.
Stuff and Nichols (1989)	45	16 - 36 weeks. Houston metropolitan area. Middle and upper income groups.	Data available on individual infants. Initially exclusively breast-fed; solid food introduced during identified time periods.
Dewey *et al.* (1991a; 1991b)	73	3, 6, 9, 12 months. Davis, California. Relatively high socioeconomic status. University community.	Data available on individual infants. Exclusively or almost exclusively breast-fed at least through 3 months and fully breast-fed through 12 months. Davis Area Research on Lactation, Infant Nutrition and Growth (DARLING study). Corrected for insensible water loss during nursing (e.g., evaporation).
Ferris *et al.* (1993)	10	7, 14, 42, 84 days. Connecticut; Massachusetts.	Data available on individual infants; exclusively and almost exclusively breast-fed infants of referent mothers in study comparing insulin-dependent, control and referent mothers.
Michaelsen *et al.* (1994)	60	2, 4, 9 months. Copenhagen, Denmark.	Summary results only. Exclusively and partially breast-fed infants. Corrected for insensible water loss.

* The value listed is that for the maximum number of mother-infant pairs in the study.

In reviewing and evaluating studies, several factors potentially affecting the accuracy of breast milk consumption estimates and their applicability to the general population were considered. These are outlined below.

5.2.1.1 Measurement of Volume of Breast Milk Consumed

In all reviewed studies, breast milk intake was measured by the test weighing method. Infants are weighed before and after breast-feeding for a given period of time (usually 24 hours) and the increases in weight from each feeding period are summed to give the total amount of milk consumed per day. The test weighing method has been consistently found to be reasonably accurate in measuring milk intake (Hofvander *et al.*, 1982; Neville *et al.*, 1988), with a small bias for underestimation. Validation studies by Brown *et al.* (1982) demonstrated that volumes obtained represent on average 95% of actual intake. Borschel *et al.* (1986) reported that intake measured by test weighing formula-fed infants was consistently lower than direct measurement (averaging 90% of direct measurement volume for 1, 2, 4 and 6 months). Some of the underestimation appears to be due to insensible water loss, described below.

5.2.1.2 Correlation with Age and Body Weight

Breast milk intake varies with age primarily due to changes in infant weight and to the addition of formula and/or solid foods to the infant's diet. One goal in selecting studies for analysis was to have adequate data on breast milk consumption at different ages during the first year of life.

Infant body weight is positively associated with breast milk intake. Dewey *et al.* (1991b) found a strong positive correlation between milk intake and infant weight at three months of age ($p<0.01$). Neville *et al.* (1988) reported that intake after the first month of age was significantly related to infant weight ($p<0.02$). Likewise, infant weights at 2, 6, 12 and 16 weeks of age were found to be significantly ($p<0.05$) correlated with breast milk intake by Matheny and Picciano (1986).

5.2.1.3 Insensible Water Loss

One source of underestimation in test weighing is the decrease in weight from insensible water loss (*e.g.,* evaporation losses). Insensible water loss during nursing leads to underestimates of milk intake of 1-5% (Brown *et al.*, 1982; Butte *et al.*, 1984a; Woolridge *et al.*, 1985; Dewey *et al.*, 1991b). In the articles reviewed on breast milk intake, a few investigators reported estimates for insensible water loss, while the majority did not. Dewey *et al.* (1991b) calculated insensible water loss to be 0.05 g/kg/min on average.

5.2.1.4 Effect of Maternal Factors on Breast Milk Intake

The correlations between breast milk intake and certain maternal factors (age, parity, pregnancy weight gain, weight, ideal weight, triceps skinfold, and weight change from one to three months postpartum) were investigated by Dewey *et al*. (1991b). No significant correlations were found.

5.2.2 Study Selection for Analysis of Milk Consumption Rates

5.2.2.1 Study Selection

The requirements for study selection were the fulfillment of the criteria for study review described in Section 5.2.1 above and the availability of intake data on a body weight and individual infant basis. Obtaining data for breast milk intake on an individual infant basis was also considered important because these data facilitate the exploration of methods to describe variability in milk consumption.

From the reviewed studies, primary investigators were contacted, where possible, to determine if data were available that met the above selection requirements. Data were obtained from Stuff and Nichols (1989); Dewey *et al.* (1991a; 1991b); Hofvander *et al.* (1982) and Ferris *et al.* (1993). Both Stuff and Nichols (1989) and Dewey *et al.* (1991a; 1991b) provided data on milk intake for infants three months or older. For data on infants aged 3 to 12 months, the Dewey *et al.* study was chosen because of the large sample size and because data were available through 12 months of age. The Stuff and Nichols (1989) dataset consisted of intake data beginning at 16 weeks with subgroups of infants introduced to solid foods at designated intervals and followed for an additional 12 weeks of breast-feeding. The Stuff and Nichols (1989) subgroup of infants breast-fed for the longest period breast-fed only through 36 weeks of age and consisted of only eight infants. The Dewey *et al.* study had the advantage that the data were from a California population.

For data on early infancy, the Hofvander *et al.* study was selected because it had a larger sample size (n = 25) compared to the referent group of healthy mothers in the Ferris *et al.* study (n = 10), and because the data were available for the first two months of life, a period for which there are no data in the Dewey *et al.* study. At the three-month age group, the Hofvander *et al.* study was not statistically different from the Dewey *et al.* study and both datasets were used for this age group in our analysis. The two selected studies are described further below.

5.2.2.2 Descriptions of Selected Studies

Dewey *et al*. (1991a; 1991b) measured breast milk intake, lipid concentration and body weight at 3, 6, 9 and 12 months of age in infants in the vicinity of Davis, California. This study, frequently referred to as the “DARLING” study (for Davis Area Research on Lactation, Infant Nutrition and Growth), measured breast milk consumption of infants whose mothers planned to breast-feed for at least 12 months and did not plan to introduce solid food before four months or feed more than 120 ml/day of other milk or formula throughout the first 12 months. Mothers who participated in the study were described as of relatively high socioeconomic and educational status. Mothers did not have any chronic illness and were not taking any medication on a regular basis. Infants were described as healthy and of normal gestational age and weight. Measurements were repeated on the same infants at different ages. For the first measurement at three months, intake of 73 mother-infant pairs was measured; at six months, 60 of the initial group were sampled; at nine months, 50 infants, and at 12 months, 42 infants. Dewey *et al.* also corrected milk intake for insensible water loss which they calculated to be 0.05 g/kg/min on average. This factor was multiplied by each infant's weight and by the total time of nursing for each infant. The product, in grams, was added to the milk intake measured during the test weighing period.

Hofvander *et al.* (1982) studied milk consumption in infants aged one, two, and three months. Milk intake of 75 infants (25 at each month) was measured. Measurements were not repeated at different ages on the same infant. The study was conducted in Uppsala, Sweden (an urban center). The mothers were recruited after discharge from the hospital after delivery on the condition that their infants were single born, full term, healthy and still exclusively breast-fed. No mothers refused participation in the study. The mothers in this study were described as "older and belonging to a higher socioeconomic group" than the mothers of bottle-fed infants who also participated in the study.

Each of these studies was also noted for practices which increased the accuracy of intake measurements. Dewey *et al.* calculated their 24-hour intake values from the average of a four-day test weighing period thus decreasing the effect of day-to-day intraindividual variability on the accuracy of the results. Additionally, the Dewey *et al.* study corrected for insensible water loss. For the Hofvander *et al.* study, there was minimal selection bias because all invited mothers agreed to participate in the study. Also, no auto correlation bias occurred because there were no repeated measurements. Although Hofvander *et al*. did not appear to correct for insensible water loss, the accuracy of test weighing was assessed by repeating the 24-hour test weighing procedure with selected mothers in the hospital two to five days after test weighing at home.

5.2.3 Data Analyses and Derivation of Distributions of Breast Milk Consumption Rate

Table 5.3 below presents summary statistics for breast milk intake from the Hofvander *et al.* (1982) and Dewey *et al.* (1991a; 1991b) studies for the different age groups. Raw data (g breast milk/day and individual infant body weight) provided by Dewey *et al.* were used to calculate consumption per infant body weight whereas the Hofvander data were supplied as consumption per infant body weight. The normal distribution described these data fairly well and fit much better than log normal distributions. Maxwell and Burmaster (1993) similarly found that the normal distribution best fit consumption in their analysis of amount consumed per day. Readers are referred to Maxwell and Burmaster (1993) for the demonstration and further discussion of the normality of the Dewey *et al.* (1991a and 1991b) breast milk intake data. Note the similarity in the Hofvander *et al.* and Dewey *et al.* data from the three-month age groups. The means are not statistically different, although the spread in the Hofvander *et al.* data for this age group is slightly greater than in the Dewey *et al.* data set.

Table 5.3 Breast Milk Consumption (g/kg-day) in Fully Breast-Fed Infants

Parameter	***Approximate Age in Months***						
	Hofvander et al. (1982)*			***Dewey et al. (1991a)*****			
	1	***2***	***3***	***3***	***6***	***9***	***12***
Mean	154	148	132	130	100	74	48
Standard Error	5.0	4.6	3.7	2.1	2.5	3.4	4.2
Median	157	146	129	131	102	75	44
Standard Deviation	24.8	22.9	18.3	18.1	19.2	24.2	27.4
Kurtosis	-0.099	0.515	-0.769	-0.23	-10^{-3}	-0.38	-0.11
Minimum	102	102	97.6	85.9	47.7	27.9	2.98
Maximum	202	199	162	174	134	128	120
Skewness	-0.42	0.50	0.03	-0.07	-0.36	-0.05	0.32
Sample size	25	25	25	73	60	50	42

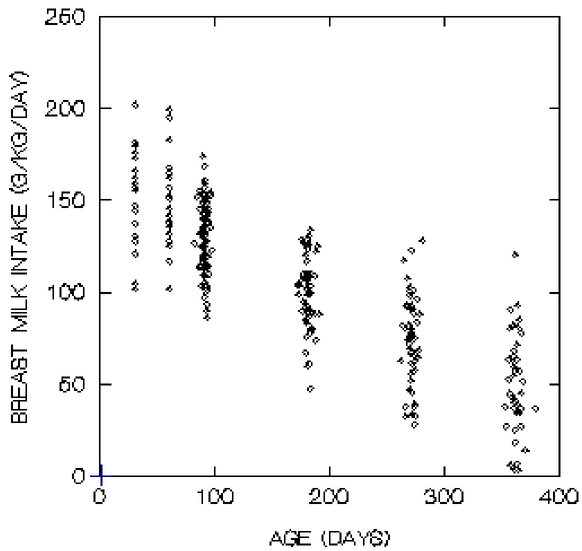
*Study conducted in Sweden measuring consumption in infants aged 30, 60, and 90 days.
**The DARLING study, conducted in Davis, California, measured consumption in infants approximately aged 3, 6, 9 and 12 months.

5.2.3.1 Statistical Description of Consumption as a Function of Age

Figure 5.1 presents the combined raw datasets of Dewey *et al.* (1991a) and Hofvander *et al.* (1982). There is considerable variability in the intakes reported at any given age, with the range (60-120 g/kg-day) and standard deviation (18-25 g/kg-day) fairly consistent among the different age groups. There is an overall trend of decreasing consumption with increasing age, with daily intake greatest during the first month of life.

The relationship between milk consumption and age was explored in model fitting exercises. Ages in days were used in all of our calculations. The individual raw data from Dewey *et al.* (1991a; 1991b) gave the exact age of the infant for each milk intake measurement, and these pairs of age-intake data were used in fitting functions. The Hofvander *et al.* data were reported as measured at 30, 60 or 90 ± 7 days of age. For calculation purposes, it was assumed that infants in this study were exactly 30, 60, or 90 days of age when measurements were taken.

Figure 5.1 Breast Milk Intake by Age for Combined Dewey et al. (1991a) and Hofvander et al. (1982) Datasets.

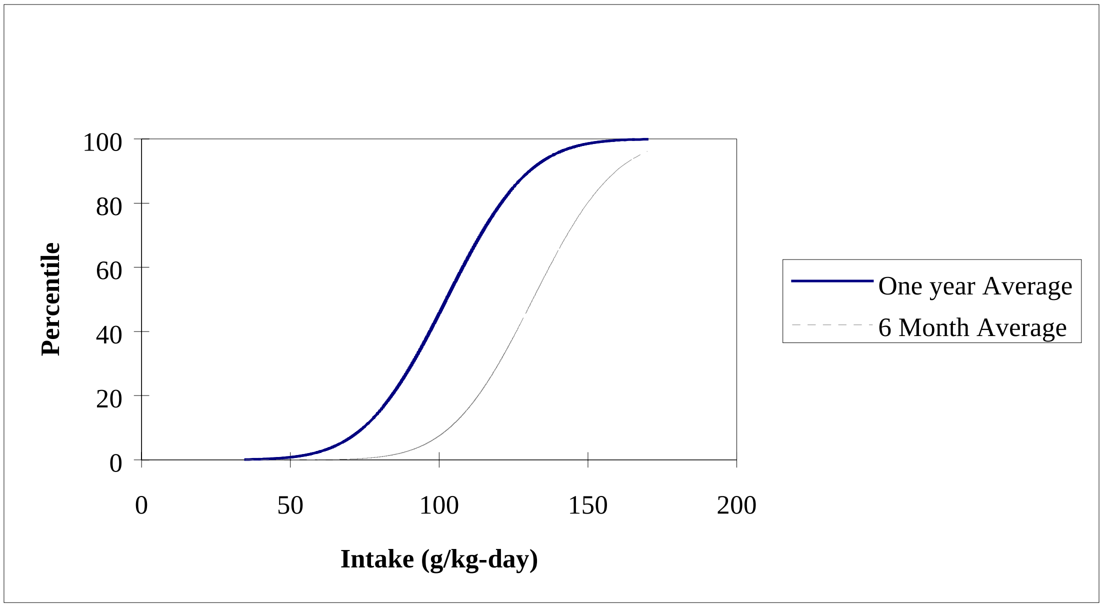


A linear relationship fits the age versus consumption rate data fairly well. From this combined data set, an intake averaged across breast-feeding infants during the first year of life is estimated to be 102.4 g/kg-day. Assuming a normal distribution of intake among the infants in this population (with mean and standard deviation 102.4 and 21.82 g/kg-day, respectively), the different levels of intake are derived and provided in Table 5.4 and graphically presented in Figure 5.2. Similarly, an estimate of average intake during the first 6 months of life is estimated to be 131.4 g/kg-day.

Table 5.4 Distribution of daily breast milk intake (g/kg-day) for fully breast-fed infants during their first 6 months or year

Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
6 months	95.5	103	109	113	116	120	123	131	140	143	146	150	154	159	167	182
12 months	66.5	74.3	79.7	84.1	87.7	90.9	94.0	102	111	114	117	121	125	130	138	153

Figure 5.2 Average Daily Breast Milk Intake for Fully Breast-fed Infants (Cumulative Distribution) from Hofvander et al. (1982) and Dewey et al. (1991a) Studies.



5.2.4 Comparison to Results Reported for Other Breast Milk Intake Studies

In Table 5.5, breast milk consumption in the Hofvander *et al.* and Dewey *et al.* studies is compared to consumption in studies of exclusively and almost exclusively breast-fed infants. Table 5.5 includes only studies for which data were available on a body weight basis (outlined in Table 5.2 above). While discussed below, results from Borschel *et al.* (1986) are omitted because infants in this study were not described as exclusively breast-fed. In the Ferris *et al.* study, infants were exclusively breast-fed at 42 days (n = 10) and almost exclusively breast-fed at 84 days (n = 10) (Neubauer *et al.*, 1993). Note that in Dewey *et al.* (1991a) three months was the only age at which all infants in this study were exclusively or almost exclusively breast-fed.

Table 5.5 Comparison of breast milk consumption values (g/kg-day) of Dewey et al. And Hofvander et al. to those for studies with exclusively or almost exclusively breast-fed infants [a]

Study	*Infant Age in Approximate Months*								
	1	***1.5***	***2***	***3***	***4***	***5***	***6***	***9***	***10-12***
Hofvander *et al.* (1982)	154 ± 25 (25)		148 ± 23 (25)	132 ± 18 (25)					
Dewey *et al.* (1991a)[a]				130 ± 18 (73)			100 ± 19[b] (60)	74 ± 24[b] (50)	48 ± 27 [b] (42)
Butte *et al.* (1984a)	159 ± 24 (37)		129 ± 19 (40)	117 ± 20 (37)	111 ± 17 (41)				
Salmenpera *et al.* (1985)[c]					125 ± 21 (12)		113 ± 17 (31)	108 ± 20 (16)	106 ± 19 (10)
Stuff and Nichols (1989)					114 ± 18 (45)	103 ± 22 (26)	107 ± 27 (8)		
Ferris *et al.* (1993) (referent group)		131 ± 22 (10)		112 ± 20 (10) [d]					
Michaelsen *et al.* (1994)			140 ± 24 (60)		124 ± 17 (36)				

[a] The number of mother-infant pairs is given in parentheses. Intakes are reported as arithmetic mean ± standard deviation.
[b] For age groups 6, 9, and 12 months the infants in the study by Dewey *et al.* were fully but not exclusively breast-fed.
[c] Salmenpera *et al.* (1985) reported values as ml/kg-day, which were converted to g/kg-day by OEHHA by multiplying by 1.03.
[d] Measurements were at 84 days infant age but categorized with the 3 month age group for comparison purposes.

Note that for the one-month age group, results of the Hofvander study are nearly identical to those of Butte *et al.* (1984a). They are also similar to other values for exclusively breast-fed infants during the first month reported in the literature. At 7 and 14 days, for the Ferris *et al.* (1993) referent group of healthy mother-infant pairs, intake was calculated as 148 ± 38 g/kg-day (n = 10) and 161 ± 42 g/kg-day (n = 9), respectively. Borschel *et al.* (1986) reported intake at one month as 158 ml/kg-day (163 g/kg-day) a time when it is likely that all infants in the study were exclusively or almost exclusively breast-fed. Comparisons could also be made with calculated estimates of average intake on an average body weight basis. Using group average intake and weights reported by Pao *et al.* (1980), an estimated intake per body weight is calculated as 177 g/kg-day at one month (n = 11). Using group average infant weight and intake reported by Kohler *et al.* (1984), an estimated intake of 160 g/kg-day at 6 weeks (n = 26) is calculated.

For the two-month age group, results from Hofvander *et al.* (1982) are consistent with those of Michaelsen *et al.* (1994) but somewhat higher than those reported by Butte *et al.* (1984a). Although eight infants in the Butte *et al.* study received one or more supplemental feedings, supplements for all but one appeared to be inconsequential. The degree, if any, to which these feedings affected summary results is not known. Borschel *et al.* (1986) reported intake at two months as 128 ± 7 ml/kg-day (132 ± 7 g/kg-day), but did not identify the 15 infants in this study as exclusively breast-fed or discuss supplemental feeding. However, nursing frequency was lower in this study compared to other reviewed studies (Butte *et al.*, 1984a; Dewey *et al.,* 1991b; Michaelsen *et al.,* 1994) which may suggest some supplementation with solid foods.

For the three month age group, results of the Hofvander *et al.* and Dewey *et al.* studies are somewhat higher than those for Butte *et al.* (1984a) and Ferris *et al.* (1993). Some of this difference may be explained by the fact that both of these latter studies included infants receiving small amounts from supplemental feedings at this age whereas infants in the Hofvander *et al.* and Dewey *et al.* studies were exclusively or almost exclusively breast-fed during this time.

It should be noted that only Dewey *et al.* (1991a; 1991b) and Michaelsen *et al.* (1994) corrected for insensible water loss which may explain their slightly higher reported consumption rates. A correction for insensible water loss would bring the data from Butte *et al.* (19984a) and Stuff and Nichols (1989) for the four-month age group in line with those of Michaelsen *et al.* (1994) but would correspondingly increase the values for the Salmenpera *et al.* study.

At six months, results of Salmenpera *et al.* (1985) are somewhat higher than those of Dewey *et al.* reflecting the fact that all infants in the Salmenpera *et al.* study were exclusively breast-fed, whereas at six months, none of the infants in the Dewey *et al.* study were exclusively breast-fed. At nine and twelve months, consumption rates differed markedly between the Salmenpera *et al.* and Dewey *et al.* studies. This difference reflects both solid food intake in the Dewey *et al.* study as well as that some infants in the Dewey *et al.* study were in the process of weaning.

5.2.5 Annual Average Intake for Exclusively versus Fully Breast-fed Infants

The analysis above produced a distribution of intake levels for fully breast-fed infants (defined in Section 5.1). Comparable estimates of intake levels for exclusively breast-fed infants can be derived from the Salmenpera *et al.* (1985) study (infants from 4 - 12 months of age) and the corresponding study of Hofvander *et al.* of infants from one to three months of age. Analysis of this combined dataset gives an estimated mean daily intake for exclusively breast-fed infants in their first year of life of 124 g/kg-day. Adjusting for insensible water loss results in an estimate of 130 g/kg-day, assuming 5% underestimation of milk intake from this source. These estimates are considerably greater than the rate of 102.4 g/kg-day obtained above for infants exclusively breast-fed through at least three months of age and receiving solid foods some time after three months (*i.e.,* from the combined Hofvander *et al.* and Dewey *et al.* dataset).

It should be noted that Salmenpera *et al.* (1985) reported a slower growth rate (in length) of exclusively breast-fed infants compared to infants who received complementary foods. The authors of this study could not determine whether the slower growth rate represented appropriate physiological growth or whether it indicated nutritional deficiency. Ahn and MacLean (1980) found that growth of exclusively breast-fed infants through the ninth month of life was comparable to the standard reference growth rates compiled by the National Center for Health Statistics.

5.2.6 Effect of Solid Food Introduction and Weaning on Estimates of Breast Milk Intake

The American Academy of Pediatrics regards breast-feeding as the optimal form of infant nutrition (American Academy of Pediatrics, 1982) and has recently changed their policy to recommend exclusive breast-feeding through the first six months of life, and the continuation of breast-feeding through at least 12 months of infant age with the introduction of solid foods in the second half of the first year of life (American Academy of Pediatrics, 1997).

The combined datasets used in this analysis describe breast milk consumption in exclusively breast-fed infants through at least three months and in infants breast-fed during the period of solid food introduction, some of whom continued to breast-feed through 12 months of age. In light of the new recommendations of the American Academy of Pediatrics, it would have been desirable to analyze data in which infants were exclusively breast-fed for the first six months (and introduced to solid foods in the latter half of the first year) since milk intake clearly decreases with the introduction of solid foods. However, no individual data for such infants were available. In Dewey *et al.* (1991a; 1991b), infants were introduced to solid foods some time after three months of age (mean 5.3 ± 1.1 months).

We calculated a mean breast milk intake value of 48 g/kg-day at 12 months from the Dewey *et al.* (1991a) study. Of the 42 infants in the study at this point, five consumed 6.5 g/kg-day or less with a minimum intake value at 2.98 g/kg-day. These infants can be considered "token breast feeders" (Table 5.1). Breast milk was not a significant source of nutrients or calories for these infants, and represented less than 5% of the RDA for this age infant. While there is a considerable range in intake for the other infants in this study (13.9 - 120.3 g/kg-day) who may have been in the process of weaning, these five infants appear to be essentially weaned and breast-fed solely for comfort. Also, the inclusion criteria for the Dewey *et al.* study (less than 120 ml/day of other milk) could not have been met for these five infants at 12 months. The marked decline in breast milk intake at 12 months (48 g/kg-day) is at least in part due to the inclusion of token breast-feeders in the analysis.

5.2.7 Representativeness of Estimates of Breast Milk Consumption

The mother/infant pairs included in our dataset were predominantly white, well-nourished and of relatively high socioeconomic and educational status, and therefore do not represent a cross-section of Californians. However, breast milk volume appears to be similar among all women except those who are severely malnourished as discussed below.

Breast milk production was found to be lower among poorly nourished mothers in underdeveloped countries (Jelliffe and Jelliffe, 1978; World Health Organization (WHO), 1985). But others have reported that milk intake in industrialized countries is similar to that of developing countries (Brown *et al.*, 1986; National Research Council, 1991). In their review of the literature, Ahn and MacLean (1980) concluded that "methodological difficulties resulted in conflicting information" but that studies generally agreed "that the milk output of mothers in both environments is comparable, except in populations of markedly undernourished women."

In most cases, volume of breast milk ingested is considerably less than the mother's potential supply (WHO, 1985).

Lower breast milk consumption reported by Jelliffe and others may actually reflect lower birth weights of infants in developing countries (Whitehead and Paul, 1981; Brown *et al.*, 1986). Brown *et al.* (1986) reported that while the absolute amount of milk produced appeared to be lower in marginally nourished Bangladeshi mothers, breast milk consumption relative to infant body weight was actually slightly greater than in exclusively breast-fed North American infants.

5.3 Breast Milk Consumption in the General Population

The distribution of breast milk intake for fully breast-fed infants derived above (see Figure 5.2; Table 5.4) can be used with data on breast-feeding duration to derive a distribution of breast milk intake for the general population (i.e., including infants who were never breast-fed). Data on the duration of breast-feeding, provided by Ross Products Division of Abbott Laboratories, are discussed below. These data were used to derive the distribution of breast milk consumption among the entire infant population (Section 5.3.2).

5.3.1 Duration of Breast-Feeding

The majority of American newborns are breast-fed. The Ross Mothers' Survey (1996), an annual nationwide mail survey, reported that in 1995, 59.7 % of newborns were breast-fed in-hospital nationwide and 21.6% of infants were breast-fed at six months of age. The survey has consistently found that the percent of mothers breast-feeding in the United States varies considerably with geographic region. The highest rates of breast-feeding are in the Mountain and Pacific states (U.S. census regions). In the Pacific states in 1995, 75.1% of newborns were breast-fed in-hospital, and 30.9% of infants were breast-fed at 6 months (Ross Products Division, Abbott Laboratories, 1996).

The Mothers' Survey, conducted by Ross Products Division of Abbott Laboratories (1996), is based on recall and is mailed to new mothers at the time that their infants are six months of age. Mothers are asked to recall whether they had breast-fed during month six and in the five previous months including in-hospital (i.e., during their hospital stay following delivery). In the 1995 survey, questionnaires were mailed to approximately 725,000 new mothers with a response rate of approximately 50%. Rates of breast-feeding reported in the Ross Mothers' Survey are consistent with rates reported in the National Surveys of Family Growth (Ryan *et al.*, 1991).

Additionally, Ross Products Division mails questionnaires to mothers when their infants are 12 months of age. As in the six-month survey, mothers are asked to recall whether they had breast-fed during month 12 and in the five previous months. The mothers who respond to the survey at 12 months are not necessarily the same mothers who respond at 6 months (personal communication, Ross Products Division, Abbott Laboratories).

In Table 5.6 below, data for the Pacific states from the 1995 surveys at 6 and 12 months of infant age are combined to show the percentage of infants being breast-fed from birth through

12 months (also shown in Figure 5.5). We note the discrepancy between months 6 and 7 which may, in part, be due to different mothers responding to the survey at 6 and 12 months and to difficulties in recalling earlier breast-feeding practices.

Table 5.6 Percentage of All Mothers Breast-feeding in 1995 by Age of Infant (Ages 0-12 months) in the Pacific Census Region*

Age	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
Percentage	75.1	64.8	56.5	47.8	40.0	34.9	30.9	32.1	23.9	21.0	18.7	16.2	13.7

*Data provided by Ross Products Division, Abbott Laboratories. 1996.

In addition to geographic differences, breast-feeding patterns vary considerably with maternal age and education, race/ethnicity, and economic status (National Research Council, 1991; Ross Products Division, Abbott Laboratories, 1996). The initiation and duration of breast-feeding in all of these categories has steadily increased over the last five years. The increase has been most noteworthy among groups who have traditionally had the lowest prevalence of breast-feeding. We discuss these increases, in both initiation and duration, in Section 5.5 below.

5.3.2 Distribution of Breast Milk Intake Among the Entire Infant Population

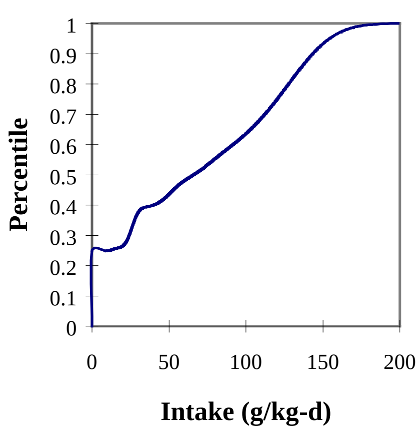
The data on intake of fully breast-fed infants and duration of breast-feeding in the Pacific states (Table 5.6) are used to derive distributions of breast milk intake among the entire infant population (breast-fed and never breast-fed infants) (Table 5.7 and Figure 5.3). In deriving risk estimates, the data in Table 5.7 are only to be used to assess risk (e.g., cancer burden) from the breast milk pathway spread over the entire (breast-fed and never breast-fed) infant population. It is to be noted that the distribution includes infants never exposed (i.e., never breast-fed) and therefore not contributing to the overall population risk. The arithmetic mean of this distribution is 43 g/kg-day for the first 12 months, and 69 g/kg-day for the first six months. Note that this distribution is not assumed to be normal and thus the means differ from the values for the 50th percentile shown in Table 5.7.

Table 5.7 Distribution for daily breast milk intake (g/kg-day) averaged over the first 6 months and 12 months of life for the general infant population (All infants, including never breast-fed)

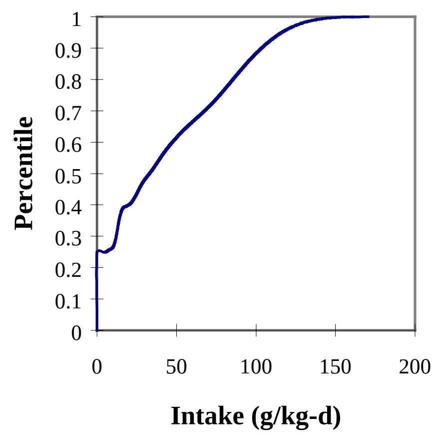
Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
6 months	0	0	0	0	11	24	28	66	103	112	120	128	135	143	154	173
12 months	0	0	0	0	5.6	12	14	33	57	68	77	86	94	103	116	137

Figure 5.3 Cumulative distributions for breast milk intake - All infants including never breast-fed - Average intake during 6 and 12 months

6 Month Average



12 Month Average



5.4 Lipid Concentration and Distribution of Lipid Intake

5.4.1 Lipid Content of Breast Milk

Many agents of concern in breast milk are delivered primarily via the constituent breast milk lipid. The lipid composition of breast milk varies among individuals. Some researchers have reported monthly increases in breast milk lipid during the breast-feeding period (Ferris *et al.* 1988; Clark *et al.* 1982) while others have found that breast milk lipid does not change significantly over time (Butte *et al.* 1984b; Dewey and Lonnerdal, 1983). Mean reported values from various studies are provided in Table 5.8.

Table 5.8 Lipid Content of Breast Milk Reported by Various Researchers

Study	***Study Findings***
Butte *et al.* (1984c)	3.92 g lipid /dl - mean for preterm infants 4.31 g lipid /dl - mean for full term infants For infants aged 2 to 12 weeks. 13 full term and 8 preterm infants. Measurements taken at 2, 4, 6, 8, 10, 12 weeks postpartum. No significant changes in content noted over time. Standard deviations ranged from 0.78 to 1.57 g lipid /dl.
Clark *et al.* (1982)	Mean total lipid content in units g/100 ml increased between 2 and 16 weeks postpartum for 10 subjects: 3.9, 4.1, 4.6 and 5.2 at 2, 6, 12, and 16 weeks postpartum.
Ferris *et al.* (1988)	Mean lipid in g/100 ml were 3.98, 4.41, 4.87, and 5.50 at, respectively, 2, 6, 12, and 16 weeks postpartum in 12 subjects. Standard deviations ranged from 0.99 to 1.09 g/100 ml.
Dewey and Lonnerdal (1983)	Overall mean lipid content ranged from 4.3 to 4.9 g/100 ml 1-6 months postpartum, without significant differences at different months. Standard deviations ranged from 0.97 to 1.96 g/100 ml. Measurements taken at 1, 2, 3, 4, 5, and 6 months postpartum. Number of subjects at each month ranged from 13 to 18.

Inter- and intraindividual variation of lipid content over time should be considered when evaluating lipid intake for the infant population. For this report, the average lipid content of breast milk is assumed to be 4%.

5.4.2 Distribution of Lipid Intake

Under the assumption that 4% of breast milk is lipid, distributions for lipid intake are generated and tabulated below. Mean lipid intake for the fully breast-fed population during their first year of life is estimated to be 4.1 g/kg-day, with a standard deviation of 0.87 g/kg-day.

Table 5.9 Daily lipid intake (g/kg-day) via breast milk averaged over the first 6 or 12 months of life

Fully breast-fed infants

Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
6 months	3.8	4.1	4.4	4.5	4.7	4.8	4.9	5.3	5.6	5.7	5.8	6.0	6.2	6.4	6.7	7.3
12 months	2.7	3.0	3.2	3.4	3.5	3.6	3.8	4.1	4.4	4.6	4.7	4.8	5.0	6.5	5.5	6.1

General population, including never breast-fed

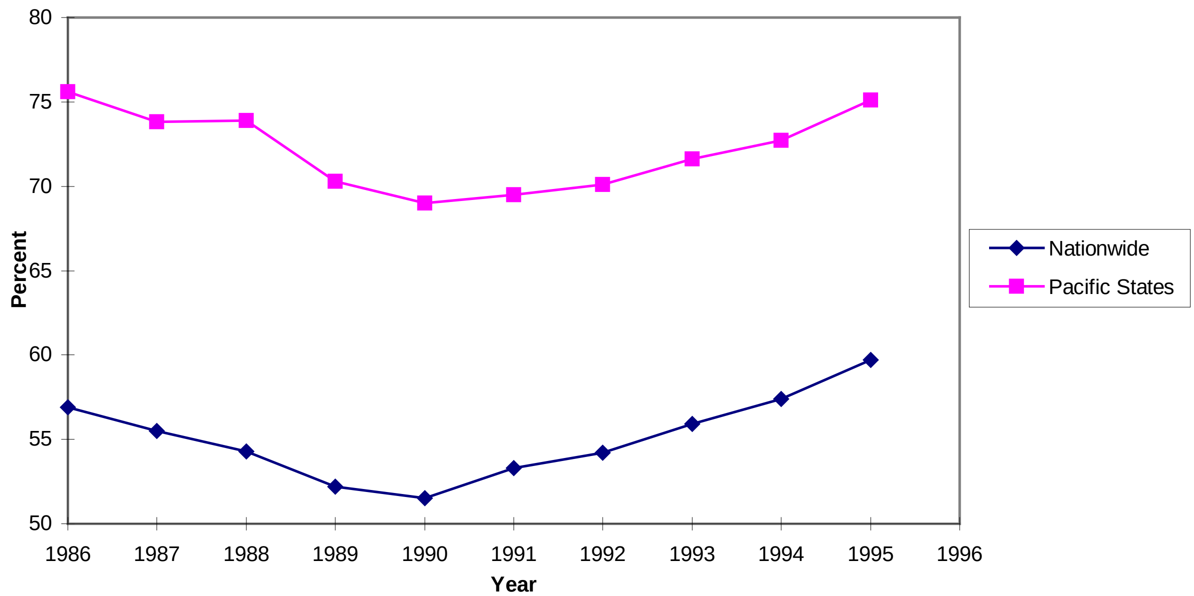
Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
6 months	0	0	0	0	0.4	1.0	1.1	2.6	4.1	4.5	4.8	5.1	5.4	5.7	6.2	6.9
12 months	0	0	0	0	0.2	0.5	0.6	1.3	2.3	2.7	3.1	3.4	3.8	4.1	4.6	5.5

5.5 Concluding Remarks

5.5.1 Trends in Breast-feeding

The number of mothers nationwide who initiated breast-feeding after hospital delivery steadily increased from 1991 to 1995 after a decline in breast-feeding from 1985-1990 (Ross Products Division, Abbott Laboratories, 1996). In 1995, the percent of mothers breast-feeding in-hospital (59.7%) was the same as in 1984, the peak year of a 13 year period of growth in the prevalence of breast-feeding. Increases in breast-feeding in the Pacific States parallel the nationwide trend. Figure 5.4 below shows the trend of mothers breast-feeding in hospitals nationwide and in the Pacific region for 1986-1995 (Ross Products Division, Abbott Laboratories, 1994, 1996).

Figure 5.4 Percentage of Mothers Breast-feeding in the Hospital After Infant Birth Nationwide and in the Pacific Region (1986-1995)



The percent of infants being breast-fed at 5-6 months of age similarly increased from 1991 to 1995. In 1995, 23.2% of infants were breast-fed at 5-6 months of age nationwide compared to 17.6% in 1990. A similar increase in duration was observed in the Pacific States. Table 5.10 details the initiation and duration of breast-feeding in the Pacific States by race/ethnicity for the years 1989 and 1995. While initiation and duration of breast-feeding has increased for all infants, the greatest increases are among African-American and Hispanic women, populations where breast-feeding rates have been the lowest.

Table 5.10 Percent of Breast-fed Infants of Different Ages in the Pacific Census Region by Race/Ethnicity

Population	***Infant Age (in months)***								
	1989 Survey[a]		***1995 Survey***[b]						
	0	***5-6***	***0***	***1***	***2***	***3***	***4***	***5***	***6***
All infants	70.3	28.7	75.1	64.8	56.5	47.8	40.0	34.9	30.9
Caucasian	76.7	33.4	80.4	70.0	62.0	53.1	45.1	39.5	35.4
Asian	--	--	74.7	66.8	57.7	47.5	39.4	33.8	29.5
Hispanic	58.5	19.7	67.9	56.6	47.6	39.4	32.3	28.0	24.4
African-American	43.9	15.0	59.1	50.9	43.2	35.5	28.8	24.3	21.4

[a] From National Research Council (1991).
[b] From Ross Products Division, Abbott Laboratories, personal communication, 1996.

Education and socioeconomic status have also been correlated with both initiation and duration of breast-feeding (National Research Council, 1991; Ross Products Division, Abbott Laboratories, 1996**)**. The 1995 Mothers' Survey (Ross Products Division, Abbott Laboratories, 1996) found that the largest increases in breast-feeding were among low-income, poorly educated women.

Because there are trends towards increases in breast-feeding, prevalence and duration of breast-feeding should be re-evaluated periodically.

5.5.2 Subpopulations of Special Concern

5.5.2.1 Infants Breast-fed for an Extended Period of Time

Although most infants in the United States are weaned during the first year, there is a population of infants who are breast-fed for an extended period of time. Sugarman and Kendall-Tackett (1995) found that among a group of American women (n = 179) who practiced extended breast-feeding, the age of weaning averaged between 2 1/2 and 3 years, with a high end value of 7 years 4 months. Forty-three percent of children in this sample were breast-fed beyond their third birthday. For this subpopulation of infants, exposure to environmental toxicants via breast milk would be greater than for infants with breast-feeding patterns similar to those studied in Dewey *et al.* (1991a; 1991b).

Documentation of extended breast-feeding is quite limited in this country both because there is little socio-cultural support for extended nursing and because many health care practitioners do not consider asking about it (Sugarman and Kendall-Tackett, 1995). However, recent increases in the duration of breast-feeding as well as efforts by public agencies and the American Academy of Pediatrics to promote and support breast-feeding (Section 5.53) would suggest that the numbers of infants being breast-fed beyond the first year of life may be increasing as well.

Exposures to infants who are breast-fed for an extended period of time should be further investigated and in some circumstances taken into account in non-default analyses.

5.5.2.2 Infants of Older Mothers

The Ross Mothers Survey found that both initiation and duration of breast-feeding increased with maternal age (Ross Products Division, Abbott Laboratories, 1996). In the 1995 nationwide survey, 52.6% of mothers ages 20-24 initiated breast-feeding in the hospital, and 15.8% were breast-feeding at 5-6 months of age. In comparison, 68.1% of mothers 30-34 years of age initiated breast-feeding in the hospital and 31.1% were breast-feeding at 5-6 months postpartum. Among mothers 35 years of age and older, 70% initiated breast-feeding and 35.8% were breast-feeding at 5-6 months postpartum (Ross Products Division, Abbott Laboratories, 1996). No data are available for the Pacific States, but it is likely that for each of these age groups, increases in initiation and duration reflect differences in breast-feeding rates between the Pacific States and the U.S. nationwide (shown below in Figure 5.6).

Older primiparous mothers have accumulated greater quantities of highly lipophilic, poorly metabolized toxicants in adipose tissue than younger mothers. During the breast-feeding period, infants of older primiparous mothers will receive greater daily doses of these contaminants from breast milk than infants of younger mothers. Furthermore, because older mothers tend to breast-feed for a longer duration than younger mothers (as noted in the paragraph above), their infants may receive much greater quantities of these environmental toxicants than infants of younger mothers.

There are increasing trends towards older women giving birth. In California, 35% of births recorded in 1994 were to women 30 years of age or older and over 12% were to women 35 years or older (California Department of Health Services, 1996). Thus, it is important to consider maternal age in assessing infant exposure to highly lipophilic, poorly metabolized contaminants.

5.5.2.3 Estimates for High-end Consumption

Under certain circumstances, information on the number of individuals exposed at various levels is of interest. For assessing large population exposures, Table 5.11 may be of use. It indicates the number of infants in California consuming at upper end breast milk and lipid intake levels.

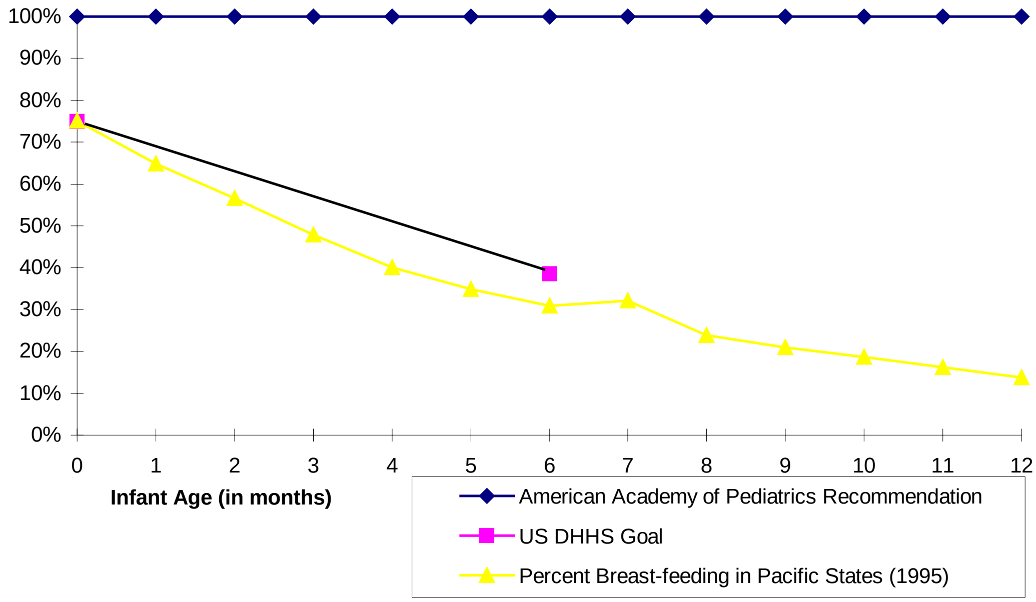
Table 5.11 Intake estimates for the general infant population in California

Number of infants at equivalent or greater intake	*Lipid Intake (g/kg-day)*		*Breast Milk Intake (g/kg-day)*	
	6 month average	*1 year average*	*6 month average*	*1 year average*
6,140 (99th percentile)	6.9	5.5	173	137
615 (99.9th percentile)	7.7	6.4	192	161

5.5.3 Promotion of Breast-feeding

Increases in the percent of mothers breast-feeding and in the duration of breast-feeding may partially result from recent efforts in the public health community to encourage breast-feeding. In 1984, the U.S. Surgeon General set a nationwide goal for increasing the initiation and duration of breast-feeding to 75% at the time of hospital discharge and to 35% at 6 months postpartum by the year 1990. The importance of breast-feeding was incorporated into the U.S. Department of Health and Human Services “Healthy People 2000” Program, which set a nationwide goal of increasing the initiation of breast-feeding to 75% in the early postpartum period and to 50% the proportion of mothers who continue breast-feeding their babies through five to six months of age. Most recently, the American Academy of Pediatrics (1997) has issued a new policy statement on breast-feeding in which it recommends exclusive breast-feeding for six months and continuation of breast-feeding through at least the first year of life. These goals and recommendations are shown in Figure 5.6 along with the prevalence of breast-feeding during the first 12 months of life in the Pacific States.

Figure 5.5 Percent Breast-feeding in Pacific states (1995) Compared to "Healthy People 2000" Program Nationwide Goal and Recommendation of the American Academy of Pediatrics.



Efforts have also been underway to change certain hospital practices that impede successful breast-feeding. Some of the practices associated with lower rates of breast-feeding include the separation of mother and infant, delays in getting the infant to the breast, and the provision of formula both in the hospital and in discharge packs (Wright *et al.*, 1996). In 1991, the World Health Organization and the United Nations Children's Fund launched the Baby-Friendly Hospital Initiative (BFHI), a ten step program to promote breast-feeding by changing hospital practices. Although the BFHI was immediately supported internationally, implementation of the program has been slower within the United States. As of 1995, over 200 U.S. hospitals had filed intents to be designated as "baby friendly" and other less formal efforts were underway at hospitals throughout the country (Wright *et al.*, 1996).

The effect of the BFHI on breast-feeding outcomes and its acceptance (both by means of certification and informal programs) in American hospitals will probably be documented in the next few years. Other programs to promote breast-feeding have also been initiated in recent years. Cohen and Mrteck (1994) reported that in a workplace program that provided lactation rooms for working women, these mothers breast-fed as long as non-working mothers. These efforts to support breast-feeding may also help to make breast-feeding more socially and culturally acceptable. Morse and Harrison (1987) found that among women who are successfully breast-feeding, it is the attitude of others which determines time of weaning, an attitude that they refer to as the “social coercion for weaning”.

The 1997 American Academy of Pediatrics policy statement also delineates various ways in which the pediatric community can promote and encourage breast-feeding. These recommendations will likely result in more mothers breast-feeding and in greater numbers of mothers breast-feeding for longer time periods. Active support for breast-feeding by pediatricians, combined with the hospital and workplace programs discussed above, may significantly increase both the initiation and duration of breast-feeding.

5.5.4 Conclusion

Breast-feeding is an important indirect pathway of exposure for environmental contaminants, particularly persistent lipophilic chemicals. Significantly larger quantities of lipophilic environmental contaminants stored in maternal adipose tissue are delivered to breast-fed infants compared to non-breast-fed infants. For these reasons risks through breast milk consumption should be considered carefully when evaluating the risks from environmental releases of persistent, lipophilic toxicants. This chapter provides a framework and the values needed for estimating the range of exposures to such pollutants for breast-feeding infants and the general infant population.

The benefits of breast-feeding are becoming widely recognized, and public health institutions promote and encourage breast-feeding. In most situations, the benefits for the general infant population appear to outweigh the risks from milk contaminant exposures. It is also a public health goal to minimize the risk and to understand the magnitude of the risk. Because the patterns of breast-feeding are changing, the duration of breast-feeding and intake of breast milk at different ages should be re-evaluated periodically to ensure a sound basis for such calculations.

5.6 Recommendations

OEHHA recommends the following to estimate dose through breast milk.

5.6.1 Default Point Estimate for Daily Breast Milk Consumption During the First Year

As the default number for the point estimate approach to assessing dose and risk from breast milk consumption by breast-fed infants during the first year, use the mean and high-end estimates presented in Table 5.12 for fully breast-fed infants with Equation 5-3. Dose and risk evaluated using the high-end estimate should be presented if breast milk is a dominant pathway of exposure (see Chapter 1 for discussion of dominant pathways). Note that the intake rate for breast milk already incorporates body weight which is in the denominator of Eq. 5-1.

Table 5.12 Point estimates of breast milk intake for breast-fed infants

Infant Group	*Intake (g/kg-day)*
Fully breast-fed	
mean	102
95th percentile	138
Exclusively breast-fed	
During first year	
mean	127
95th percentile	161
During first 6 months	
mean	140
95th percentile	174
During first month	
mean	154
95th percentile	195

If the risk assessor wishes to calculate a point estimate for the cancer burden, which would include non-consumers, the intake distribution for the general population of infants, given in Table 5.7, might be of interest. The mean and upper 95^{th} percentile for daily intake during the first year for the general population are 43 and 116 g/kg-day, respectively. Average daily intake over the first six months (for consumers and non-consumers combined) is 69 g/kg-day; intake at the 95th percentile is 154 g/kg-day. Note that this distribution is not assumed to be normal and thus the means differ from the values for the 50^{th} percentile shown in Table 5.7.

5.6.2 Breast Milk Consumption Among Individuals during the First Year of Life

For a stochastic analysis of exposure and dose through the breast milk consumption pathway, use Equation 5-5 varying the breast milk intake rate. Use Table 5.13, or a normal distribution with mean 102.4 g/kg-day and standard deviation 21.82 g/kg-day, to characterize breast milk intake over the first year of life for breast-fed infants. With concentration information and weighting factors, this intake can be used to predict exposure and individual cancer risk for breast-fed infants. Note that the distribution incorporates body weight (the units are g/kg-day) and therefore the BW variate in the denominator of Eq. 5-1 is already taken into account.

Table 5.13 Recommended Breast Milk Consumption Among Individuals (Averaged Over an Individuals First Year of Life)

Percentile	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*50*	*65*	*70*	*75*	*80*	*85*	*90*	*95*	*99*
Intake (g/kg-day)	66.5	74.3	79.7	84.1	87.7	90.9	94.0	102	111	114	117	121	125	130	138	153

5.6.3 Consideration of Variable Age of Breast-feeding Mothers

Because accumulation of environmental toxicants is far greater in older primiparous mothers than in younger mothers, distribution of the age of breast-feeding mothers should be considered by OEHHA for incorporation with the breast milk consumption rate distributions.

5.6.4 Analysis for Population-wide Impacts from Breast Milk Exposure

If the risk assessor is evaluating a population-wide risk (e.g., for the purpose of developing a range of cancer burden estimates from this pathway), it may be appropriate to incorporate information on the percent of the infant population that is breast-fed at various ages. The information on Pacific states (U.S. census region) data from Ross Products is useful for this purpose. This information has been incorporated to derive a distribution of breast milk intake for the general infant population, in Table 5.7. This information can be used as appropriate to analyze population-wide impacts of exposure via the breast milk pathway. It should be re-evaluated periodically to take into account recent trends in breast-feeding and the outcome of the breast-feeding promotion policies of the last decade.

5.7 References

Ahn CH, MacLean WC (1980). Growth of the exclusively breast-fed infant. Am J Clin Nutr 33:183-192.

AIHC (1994). Exposure Factors Sourcebook. Washington, D.C.: American Industrial Health Council.

American Academy of Pediatrics (1997). Breast-feeding and the use of human milk. Pediatr 100(6):1035-1039.

American Academy of Pediatrics (1982). The promotion of breast-feeding; policy statement based on task force report. Pediatr 69(5):654-661.

American Academy of Pediatrics Committee on Nutrition (1993). Supplemental foods for infants. In: Pediatric Nutrition Handbook. Third Edition. Barnes LA, editor. Elk Grove, IL: American Academy of Pediatrics; pp. 23-32.

Borschel MW, Kirksey A, Hannemann RE (1986). Evaluation of test-weighing for the assessment of milk volume intake of formula-fed infants and its application to breast-fed infants. Am J Clin Nutr 43:367-373.

Brown KH, Black RE, Robertson AD, Akhtar NA, Ahmed G, Becker S (1982). Clinical and field studies of human lactation: methodological considerations. Am J Clin Nutr 35:745-756.

Brown KH, Robertson AD, Akhtar NA (1986). Lactational capacity of marginally nourished mothers: infants' milk nutrient consumption and patterns of growth. Pediatrics 78(5):920-927.

Butte NF, Garza C, Smith EO, Nichols BL (1983). Evaluation of the deuterium dilution technique against the test-weighing procedure for the determination of breast milk intake. Am J Cl Nutr 37:996-1003.

Butte NF; Garza C; Smith EO, Nichols BL (1984a). Human milk intake and growth in exclusively breast-fed infants. J Pediatr 104:187-194.

Butte NF, Garza C, Stuff JE, Smith EO, Nichols BL (1984b). Effects of maternal diet and body composition on lactational performance. Am J Cl Nutr 39:296-306.

Butte NF, Garza C, Johnson CA, Smith EO, Nichols BL (1984c). Longitudinal changes in milk composition of mothers delivering preterm and term infants. Early Human Development 9:153-162.CAPCOA (1993). CAPCOA Air Toxics Hot Spots Program Revised 1992 Risk Assessment Guidelines. October 1993.

CAPCOA (1993). Air Toxics Hot Spots Program. Revised 1992 Risk Assessment Guidelines. California Air Pollution Control Officers Association (CAPCOA). October 1993.

California Department of Health Services (1996). Vital Statistics of California 1994. August 1996.

Clark RM, Ferris AM, Fey M, Brown PB, Humdrieser KE, Jensen RG (1982). Changes in the lipids of human milk from 2 to 16 weeks postpartum. Journal of Pediatric Gastroenterology and Nutrition 1:311-315.

Cohen R, Mrtek M (1994). The impact of two corporate lactation programs on the incidence and duration of breast-feeding by employed mothers. Am J Health Promotion 8(6):436-441.

Crump KS and Howe RB (1984). The multistage model with time dependent dose pattern: applications to carcinogenesic risk assessment. Risk Analysis 4(3): 163-176.

Dewey KG; Heinig MJ; Nommsen LA, and Lonnerdal B (1991a). Adequacy of energy intake among breast-fed infants in the DARLING study: Relationships to growth velocity, morbidity, and activity levels. J Pediatr 119:538-547.

Dewey KG, Heinig MS, Nommsen MS and Lonnerdal B (1991b). Maternal versus infant factors related to breast milk intake and residual milk volume: The DARLING study. Pediatr 87(6):829-837.

Dewey KG and Lonnerdal B (1983). Milk and nutrient intake of breast-fed infants from 1 to 6 months: relation to growth and fatness. J Pediatr Gastroenterol Nutr 3(2):497-506.

DTSC (1993). Parameter values and ranges for CALTOX. Sacramento, CA: California Department of Toxic Substances Control, Office of Scientific Affairs, California Environmental Protection Agency; (DRAFT).

Ferris AM, Dotts MA, Clark RM, Ezrin M, Jensen RG (1988). Macronutrients in human milk at 2, 12, and 16 weeks postpartum. Journal of the American Dietetic Association 88(6):694-697.

Ferris AM, Jensen RG (1984). Lipids in human milk: A review. 1: Sampling, determination, and content. J Pediatr Gastroenterol and Nutr 3(1):108-122.

Ferris AM; Neubauer SH; Bendel RB; Green KW; Ingardia CJ, and Reece EA (1993). Perinatal lactation protocol and outcome in mothers with and without insulin-dependent diabetes mellitus. Am J Clin Nutr 58:43-48.

Hofvander Y; Hagman U; Hillervik C, and Sjolin S (1982). The amount of milk consumed by 1-3 months old breast- or bottle-fed infants. Acta Paediatr Scand 71:953-958.

Hoover S, Zeise L, Krowech G (1991). Exposure to environmental contaminants through breast milk: In: The analysis, communication and perception of risk. Garrick BJ, Gekler WC, editors. Advances in Risk Analysis. New York: Plenum Publishing.

Jelliffe DB, Jelliffe EFP (1978). The volume and composition of human milk in poorly nourished communities. Am J Clin Nutr 31:492-515.

Labbok M and Krasovec K (1990). Toward consistency in breast-feeding definitions. Studies in Family Planning 21:226-230.

Kohler L, Meeuwisse G, Mortensson W (1984). Food intake and growth of infants between six and twenty-six weeks of age on breast milk, cow's milk formula, or soy formula. Acta Paediatr Scand 73:40-48.

Matheny R and Picciano MF (1986). Feeding and growth characteristics of human milk-fed infants. J of the American Dietetic Assoc 86(3):327-331.

Maxwell NI, Burmaster DE (1993). A simulation model to estimate a distribution of lipid intake from breast milk during the first year of life. J Exp Analysis and Environ Epidemiol 3(4):383-406.

Michaelsen KF, Larsen PS, Thomsen BL, Samuelson G (1994). The Copenhagen Cohort Study on Infant Nutrition and Growth: breast-milk intake, human milk macronutrient content, and influencing factors. Am J Clin Nutr 59:600-611.

Montandon CM, Wills C, Garza C, O'Brian-Smith E, Nichols BL (1986). Formula intake of 1- and 4-month-old infants. J of Pediatr Gastroenterol and Nutr 5:434-438.

Morse JM, Harrison MJ (1992). Social Coercion for Weaning. In: Qualitative Health Research. Morse JM, editor. Newbury Park, CA: Sage Publications, Inc. pp.363-375.

National Research Council (1991). Nutrition During Lactation. Washington DC: National Academy Press.

National Research Council (1993). Pesticides in the diets of infants and children. Washington, D.C.: National Academy Press.

National Research Council (1993). Pesticides in the Diets of Infants and Children. NRC Committee on Pesticides in the Diets of Infants and Children. Washington DC.: National Academy Press.

Neubauer SH, Ferris AM, Chase CG, Fanelli J, Thompson CA, Lammi-Keefe CJ, Clark RM, Jensen RG, Bendel RB, Green KW (1993). Delayed lactogenesis in women with insulin-dependent diabetes mellitus. Am J Cl Nutr 58:54-60.

Neville MC; Keller R; Seacat J; Lutes V; Neifert M; Casey C; Allen J, and Archer P (1988). Studies in human lactation: milk volumes in lactating women during the onset of lactation and full lactation. Am J Clin Nutr 48:1375-1386.

Nommsen LA, Lovelady CA, Heinig MJ, Lonnerdal B, Dewey KG (1991). Determinants of energy, protein, lipid, and lactose concentrations in human milk during the first 12 mo of lactation: the DARLING study. Am J Clin Nutr 53:457-465.

Pao EM, Himes JM, Roche AF (1980). Milk intakes and feeding patterns of breast-fed infants. J Am Dietetic Assoc. 77:540-545.

Ross Products Division, Abbott Laboratories (1996). Updated breast-feeding trend. 1987-1995. Columbus, OH. Unpublished draft supplied to OEHHA by Ross Products Division, Abbott Laboratories.

Ross Products Division, Abbott Laboratories (1994). Updated breast-feeding trend: 1986-1993. Columbus, OH. Unpublished draft supplied to OEHHA by Ross Products Division, Abbott Laboratories.

Ryan AS, Rush D, Krieger FW, Lewandowski GE (1991). Recent declines in breast-feeding in the United States, 1984-1989. Pediatr 88(4):719-727.

Ryan AS, Pratt WF, Wyson JL, Lewandowski G, McNally JW, Krieger FW (1991). A comparison of breast-feeding data from the national surveys of family growth and the Ross Laboratories mothers surveys. Am J Public Health 81(8):1049-1052.

Salmenpera L, Perheentupa J, Siimes MA (1985). Exclusively breast-fed health infants grow slower than reference infants. Pediatr Res 19(3):307-312.

Smith AH (1987). Infant exposure assessment for breast milk dioxins and furans derived from incineration emissions. Risk Analysis 7(3):347-353.

Stuff JE and Nichols BL (1989). Nutrient intake and growth performance of older infants fed human milk. J Pediatr 115(6):959-68.

Sugarman M, Kendall-Tackett KA (1995). Weaning ages in a sample of American women who practice extended breast-feeding. Clin Pediatr 642-649.

U.S. EPA (1989). Exposure Factors Handbook, 1989 U.S. Environmental Protection Agency, National Center for Environmental Assessment Washington, D.C.: EPA/600/8-89/043.

U.S. EPA (1997). Exposure Factors Handbook, August 1997 U.S. Environmental Protection Agency, National Center for Environmental Assessment Washington, D.C.: EPA/600/P-95/002Fb.

Whitehead RG, Paul AA (1981). Infant growth and human milk requirements. A fresh approach. Lancet. 2:161-163.

Woolridge MW, Butte N, Dewey KG, Ferris AM, Garza C, Keller RP (1985). Methods for the measurement of milk volume intake of the breast-fed infant. in: Jensen RG, Neville MC, eds. Human Lactation: Milk Components and Methodologies. New York: Plenum; pp. 5-21.

World Health Organization (1985). The quantity and quality of breast milk. Geneva: World Health Organization.

Wright A, Rice S, Wells S (1996). Changing hospital practices to increase the duration of breast-feeding. Pediatrics 97(5):669-675.